Visualization of Uncertainty and Ensemble Data: Climate Modeling in the ViSUS System

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Summary

Climate scientists are working towards a better understanding of long-term global climate change. One key scientific objective is to better understand the relationship between changes in conditions or assumptions and the resulting impact on climate, as well as the uncertainty, or likelihood of those results. To study such relationships, scientists perform *ensemble runs,* which consist of many runs of several numerical models using perturbations of input parameters and initial conditions. These ensemble runs produce massive amounts of data; gaining scientific insight from such data is the key challenge our team is addressing. We are developing new capabilities for visually exploring and analyzing such data, and creating production quality software that is integrated into the Earth Systems Grid's (ESG) Climate Data Analysis Toolkit (CDAT). ESG is currently using this new capability in the preparation of its ongoing progress reports.

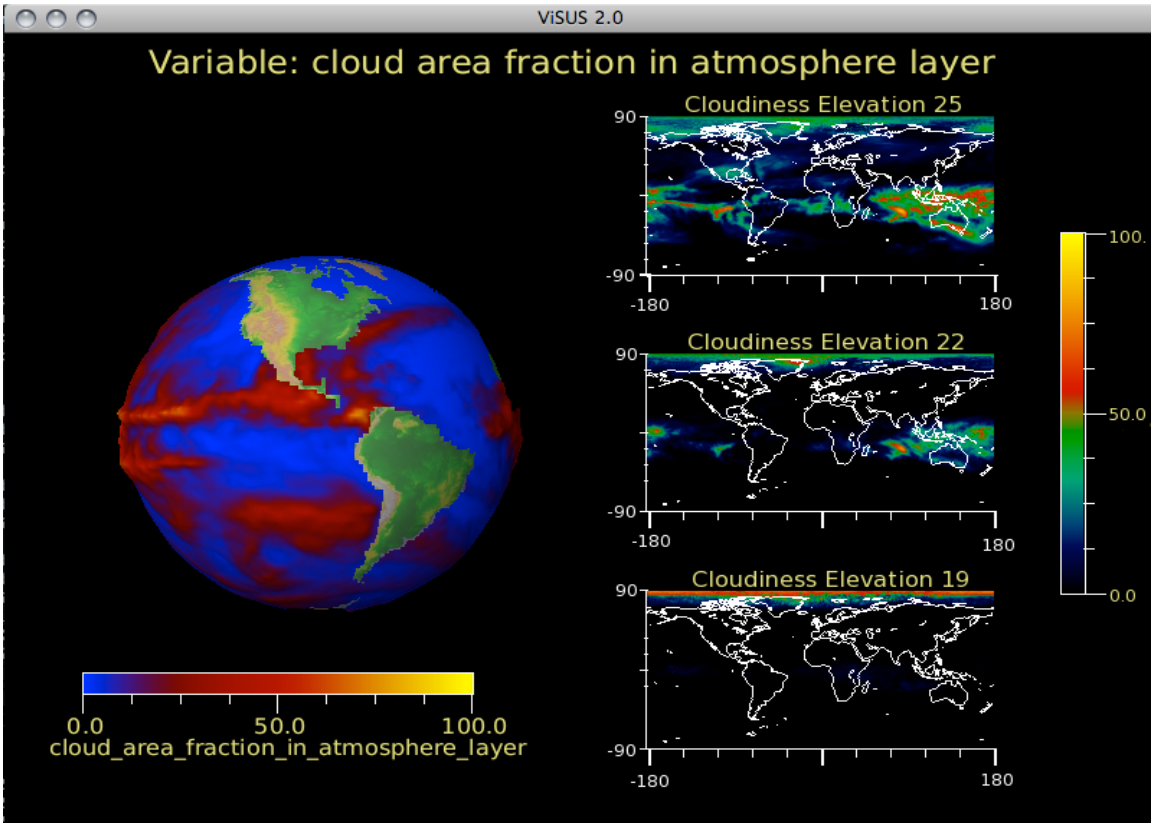

Figure 1. Screenshot of ViSUS 2.0. ViSUS provides the user with multiple views for data exploration and analysis. This lets the user investigate multiple variables simultaneously, as well as understand the uncertainty of a single variable. Here, 3 elevations of cloudiness is presented using three 2D slices, and the mean of the cloud area fraction is presented redundantly as color and height on the globe.

Climate scientists are generating large, complex datasets to model global changes in climate over long durations of time. Such datasets combine processes underlying climate behavior such as the global carbon cycle, atmospheric chemistry, vegetation, and ocean dynamics in order to better understand not only climate changes, but also the confidence level and accuracy of the simulations.

The datasets generated by climate scientists consist of multiple simulations, each run using perturbed parameters and input conditions. The result is an *ensemble* dataset, which is a collection of hundreds of simulations estimating possibly hundreds of variables per grid point, across time. These datasets quickly become quite large, on the order of terabytes of data. Such large datasets are challenging both in data management and analysis.

Ensemble datasets by design provide insight into *uncertainty.* Uncertainty can be described as the accuracy or confidence associated with the data. Errors can arise in the simulation through faulty estimations of the initial conditions, finite resolution of the numerical model, and sensitivity to parameters.

The focus of this work is to provide a new production-quality data analysis and visualization tool for collaborators with the Earth Science Grid, the Community Climate System Model Consortium, and the climate modeling community in general. Our solution provides sophisticated data analysis techniques and compelling visualizations of large, multivariate, time-varying datasets, as well as the associated uncertainty. Because of the large scale and high complexity of this type of data, data management and visualization is challenging.

Figure 1 shows representative output from the new software VACET has delivered to the climate community. This new capability is an adaptation of the ViSUS system for use in this particular application domain, in this particular delivery environment. This tool is specifically designed for the needs of climate scientists, such as reading specific data formats and providing geospatial information. VACET adapted ViSUS to integrate its 3D visualization capabilities into the Climate Data Analysis Tools (CDAT) package, which is the production visual data analysis system of the Earth Systems Grid, the Program for Climate Model Diagnosis and Intercommunication, and many others in the climate research community.

ViSUS provides a flexible system for the visualization of ensemble datasets such as those created by climate researchers. Data can be displayed using a variety of techniques, including 2D visualizations which allow for the direct comparison of multiple variables, or the variation of some dimension of a single variable. Visualizing data on the globe provides a compelling presentation, and more complex 3D techniques such as iso-surfacing. Uncertainty is displayed using height and color maps, providing visual assessment of the confidence. In addition, the time component of the data can be explored by animating the datasets through each time step.

Thus far, VACET researchers have "just scratched the surface" of what is possible. Future work will include adapting more advanced visualization and analysis of ViSUS to address the challenging data understanding needs of the climate research community.

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